Interior Design Framework Integrating Mixed Reality with the Multi-touch Tabletop Interface and Its Extension for Collocated and Remote Collaboration

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Abstract

This paper presents an interior design framework based on multi-touch table, which allows multiple users to work on. The information visualization is enhanced by 3D animation shown in a vertical display using the mixed-reality technology. Furthermore, the framework is extended to allow both collocated and remote collaboration, which is enabled by the combining of separated viewed mode and extended view mode. Moreover, a "sliding pass" touch gesture is designed for the extended mode, and a user avatar system is developed to solve the user awareness problem.

Keywords

CSCW; Mixed Reality; Multi-touch Table

Introduction

We are interested in both co-located collaboration [Hornecker 2008, Tobiasz 2009, Sadurai 2009, Cao 2010] and remote collaboration [Arroyo 2010, Tuddenham 2007, Perron 2006, Coldefy 2007] between groups using the large-scale multi-touch tabletop. Large multi-touch tabletop wall and displays is one of the most popular approaches devised for computer-supported cooperative work (CSCW) [Grudin 1994], since it offers intuitive interfaces for the team members to manipulate both shared and individual instances of data representations concurrently.

One of the most important factors in the implementation of multi-touch tabletop system for CSCW is the information visualization method. One of the related outstanding projects is Lark, presented by Matthew [Tobiasz 2009], an information visualization system for hierarchical data that supports co-located collaboration by integrating a representation of the information visualization pipeline in the shared workspace. However, many of the currently developed multi-touch tabletops confine its information visualization technology within 2D, which makes it difficult for workers to complete their work purely via the tabletop, especially for some design jobs. There are also some 3D visualization methods for multi-touch tabletop, for example, the FI3D project presented by Yu [Yu 2010]. However, most of them only support for single user instead of collaboration.

Besides, the physical constraint of most multi-touch tabletops may also bring problems for collocated collaboration. A few recent projects have investigated the possibility of physically extending the LCD based multi-touch tabletops by combining a few of LCD panels together to increase the physical size of the system such that more users can work together [Kim 2009, Wang 2008]. However, there are also some limitations with these approaches. For example, the boundaries of each LCD display explicitly divide the whole surface into small territories, which is not quite helpful for enforcing the integrity of the whole workspace. The boundaries may also cause problems when user's touch operations are across the boundaries.

As for remote collaboration, several recent projects have investigated the possibility of building linked connections among geographically-separated tabletops to create a shared. For example, VideoWhiteboard [Tang 1991] and Clearboard [Ishii 1992] provided shared drawing surfaces to let users at different location simultaneously sketch objects. Escritoire [Ashdown 2005], RemotedDT [Esenther

2006] and ViCAT/TIDL [Hutterer 2006] provide remote collaborators with another shared workspace with movable interactive virtual objects so that remote collaborators can arrange the objects at different location but still get the same experience of collocated collaboration. Although Distributed Tabletops [Tang 2006] have improved the previous work and virtual objects can be moved and reoriented by any collaborators to suit different seating arrangement, the whole shared workspace is still relatively static to collocated users. User operations could only happen on individual objects. In reality, this approach may not always be suitable for remote collaborations because the collaborations task may be divided into different sub tasks and each collocated group can choose to focus on a certain sub-area of the whole shared workspace. Thus, user operations should be implemented to support local view manipulation.

Another important factor to ensure the effectiveness of remote collaboration is user awareness. This often means to provide different kinds of cues or indicators to remind a user of the physical existence of the remote collaborators. Embodiment of collaborator is an intuitive way to represent collaborator's activities in the reference space and to enforce user awareness. Recent researches show a high interest in video-based embodiments of collaborators. In Tang's VideoArms [Tang 2006], the image of collaborators' arms is captured digitally and redrawn at the remote location to mimic collaborators' body gesture. Several other projects [Pauchet 2007, Izadi 2007, Tang 2010] also adopt this method to enable remote user awareness. These researches all assume that only one participant at each workstation uses the remote collaboration systems. However, this may not always be true in reality. For example, in a design team that includes many designers located at different cities, one designer may occupy a single tabletop at one location whereas a few designers at another location may want to share a tabletop together. Tang's research [Tang 2010] also shows that attributing workspace activity to a remote collaborator is difficult when there is more than one remote collaborator and participants are sometimes confused about whom the hand belongs to when all collaborators have the same-side configuration.

In this article, we present a conceptual interior design frame-work – multi-touch mixed reality (MTMR) which integrates the usage of mixed reality (MR) [Milgram 1994] with the multi-touch tabletop interface, providing 3D spatial information to the designers. Moreover, the proposed MTMR system is extended to a networked collaborative interior design system with the client-server architecture in order to support both efficient collocated and remote collaborations. Besides, two modes of view – Separated View Mode (SVM) and Extended View Mode (EVM) – are implemented. The SVM is aimed to address the physical constraint problem in co-located collaboration and the EVM is aimed to provide independent views of shared workspace in remote collaboration. We also develop a user avatar system to improve user awareness in remote collaboration.

Interior Design Framework

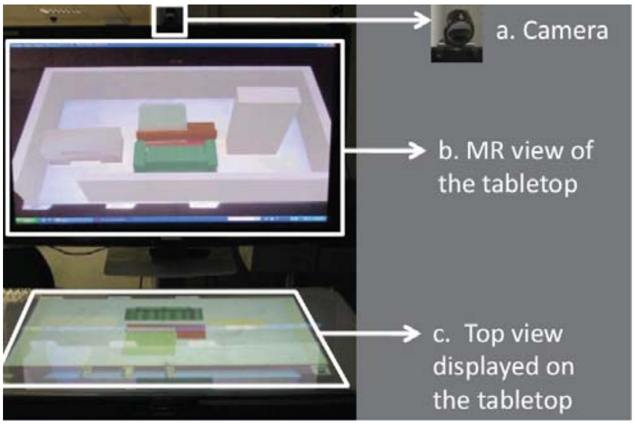


FIG. 1 OVERVIEW OF THE DESIGNER SIDE

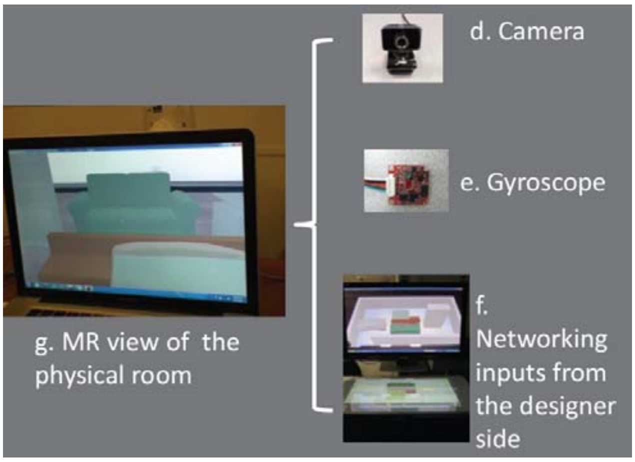


FIG. 2 OVERVIEW OF THE CLIENT SIDE

The MTMR design framework is divided into designer side (Fig. 1) and client side (Fig. 2). At the designer side, designers interact with the tabletop, and carry out design work on the top view of their design. Vertical display reflects the real-time 3D simulation of design perspective view, which provides designer better vision of their design. At client side, client resides at his/her remote home and receives designers' control messages. Client's computer will be able to interpret these control messages to construct the virtual view of the design output. The design output

which includes furniture and their orientation is combined with the camera-captured video to establish MR view. Detailed interactions at both sides are discussed in following sections.

Designer Side

The major parts of the designer side are the tabletop interface (Item *c* in Fig. 1) and the vertical display (Item *b* in Fig. 1). The tabletop interface works as both input and output device, while the vertical display shows the corresponding 3D MR view. The tabletop interface provides a multi-user multi-touch supported platform for collaborative work. Since it is convenient for the designers to carry out furniture arrangement work on 2D top views, the tabletop interface is chosen to provide the interactive environment. However, a top view alone may not provide 3D spatial information for the designers, thus the 3D MR view on the vertical screen can deliver complementary information.

Since the top view is limited in 2D, a 3D MR view of the design can provide important complementary information to the designers to review their work. The position, orientation and size of the virtual furniture contained in the tabletop display are passed through network to the computer connecting the vertical screen, where they are interpreted to construct and register 3D virtual furniture models. A camera mounted on top of the vertical screen (Item *a* in Fig. 1) captures live video of the design work going on the tabletop. This real-time video is mixed with the constructed 3D furniture models in such a way that these furniture models in the MR view align with their position, rotation and size seen in the top view. The final output is these 3D models appearing to stand on the tabletop (Fig. 4 and item *b* in Fig. 1). What is more, since the designers' operation is also captured in the video, they may look at the vertical screen while operating on the tabletop. This extra feature is expected to make the designers have the feeling that they are interacting with the 3D models directly, which would narrow the gap between the physical world and the virtual world.

Fig. 3 shows the GUI of the application at the designer side. Besides, several traditional touch gestures (translation, rotation, scaling) are implemented for touch operations. In summary, the application at the designer side supports functionalities in the following three aspects:

- Furniture model manipulation: The system provides the Model Catalogue and Trash Bin widgets for creating/deleting furniture models. Two one-finger gestures can be recognized for moving/sliding the models around inside the shared workspace and three two-finger gestures can be recognized for translating, rotating and scaling the models
- Workspace manipulation: In the shared workspace, a one-finger gesture can be used to move the entire workspace to any direction inside local workspace view. Three two-finger gestures can be used to translate, rotate and scale the entire workspace. In addition, a switchable mini-map widget is also designed for showing the area of the workspace that is visible in the local workspace.
- Two switchable collaboration modes: The system also provides both separated view mode (SVM) and extended view mode (SVM) to facilitate different collaboration needs which are switchable using the View Mode Switch widget. More details about these two modes will be provided later when collocated collaboration and remote collaboration on the MTMR system are introduced.

FIG. 3 THE DESIGN OF GUI AT THE DESIGNER SIDE

The development tool used here is MXR software development kit (SDK) which is the product of MXR Corporation (http://www.mxrcorp.com/). This SDK is built on the Torque Game Engine Advanced which is a popular commercial 3D game engine. Thus, the 3D virtual world simulation is mainly handled by TGEA source code. The modification is mainly done to facilitate creating MR effects.

The first part of 3D simulation implementation is importing 3D models for use (See Fig. 4 for example).

Furniture models used in this project are from the model database of another interior design software.

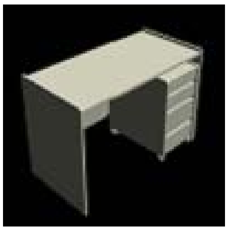


FIG. 4 PERSPECTIVE VIEW OF A FURNITURE MODEL SAMPLE

Since TEGA has its own static 3D data format dts, and the available models are in 3ds format, the first step of importing them is transferring the format using related software tool. When creating furniture models, properties such as size, location and orientation are retrieved from data sent from designer side to configure them.

The second part of 3D simulation implementation is collaboration.

FIG. 5 CALIBRATION INTERFACE

FIG. 6 CALIBRATION MARKER

Fig. 5 above shows the calibration interface. To finish the collaboration, a marker with pattern shown in Fig. 6 needs to be captured into the green ring. Then the centre of the marker will be labeled as origin (0, 0, 0), *x-y* plane is aligned with the marker's surface plane, and z axis point from the origin upwards.

For vertical display at designer side, marker is shown in the center of tabletop graphical interface. After collaboration, the marker is removed and the tabletop surface will be *x-y* plane. Thus, when *z* value of furniture model's coordinate is set to 0, the furniture will appear to be held on the tabletop as shown below.

For client side 3D simulation, the marker is placed at the center of the room floor such that the floor forms *x-y* plan. In this way, furniture models will appear to stand on the floor of the physical room.

After the coordinate system is set up, it is rather easy to match the top view design on tabletop with the 3D simulation at both vertical display and client side.

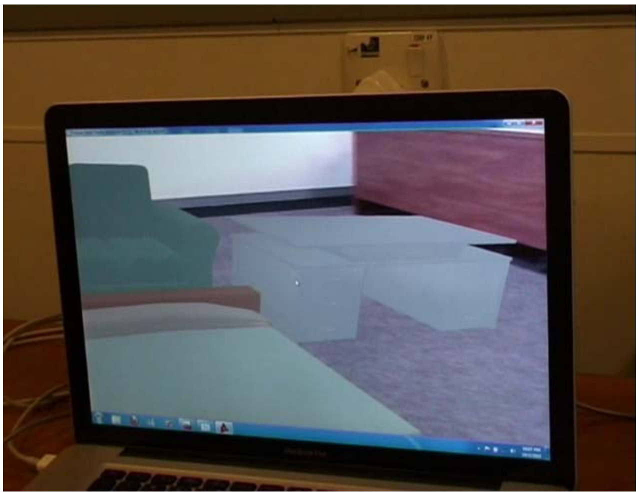
Client Side

At the client side, the implementation of MR (Item *g* in Fig. 2) is similar to the 3D MR view at the designer side. The client resides at his/her remote room and receives designers' control messages. These control messages, including the existence, position, orientation and size of the virtual furniture in the design plan, are passed to the client's computer through network (Item *f* in Fig. 2) to construct and update the client's MR view in real time. A camera (Item *d* in Fig. 2) captures live video of the client's room. This video is augmented with life-size virtual furniture models constructed according to the control messages. The difference is that at the designer side, the camera is fixed, while at the client side, the client is supposed to view the furniture layout from different perspectives with a rotatable camera. To match the perspectives of the virtual world and the physical world, an extra gyroscope (Item *e* in Fig. 2) is attached to the camera to measure its orientation. The measurement data is used to adjust the view point in the virtual world. Fig. 7 shows the same design (as in the top view in Fig. 1) viewed from three different perspectives at the client side by rotating the camera from left to right.

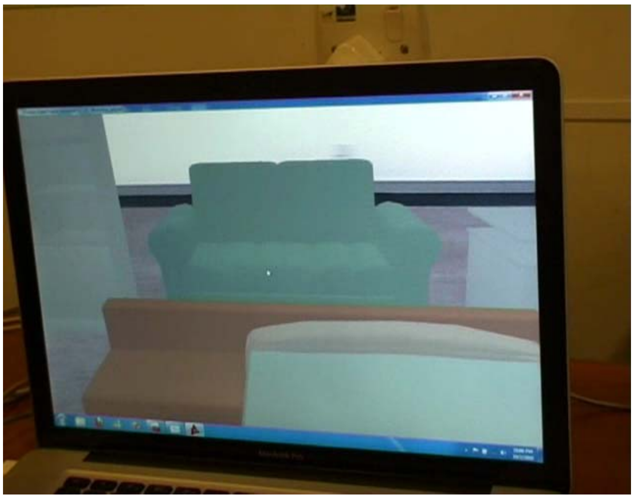
Collocated Collaboration and Remote Collaboration Using MTMR System

In the case of interior design, when the room is large, it needs more than one designer to collaborate. When the team of designers is large, the MTMR system with only one tabletop is not enough. It is important for the MTMR system to support distributed tabletops for collocated collaboration when the team of designers are in the same place and remote collaboration when they locate in different places. As mentioned in the introduction, the limited physical size is often a reason to cause unpleasant experience when too many collocated collaborators crowd around the same tabletop. As for remote collaboration, user awareness

is an important factor to ensure the effectiveness of the collaboration.



(A)



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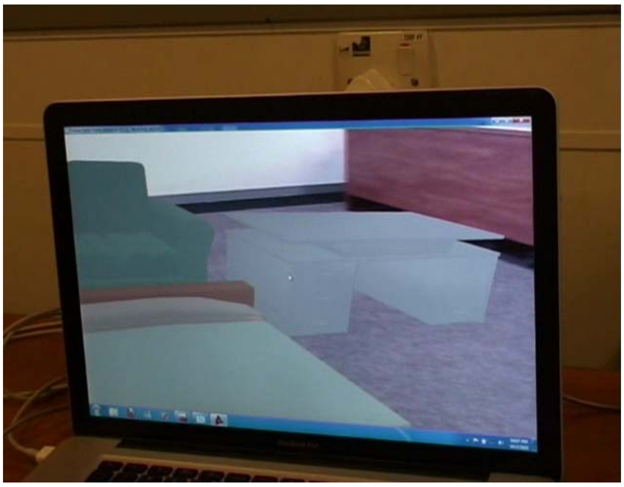


(C)

FIG. 7 (A)-(C) SHOW THE DESIGN AT THE CLIENT SIDE FROM THREE DIFFERENT PERSPECTIVES BY ROTATING THE CAMERA FROM LEFT TO TOP

Motivated by these problems, the proposed MTMR system is extended to a networked collaborative interior design system with the client-server architecture to allow efficient collocated and remote collaborations. The system provides an independent shared workspace for each collaboration task.

Network Architecture

Fig. 8 shows the architecture of the networked MTMR system. The overall system consists of a single server application named "SAPP" running on an "always-on" PC with known IP address and several instances of the client application named "CAPP" running on several workstations located at different places. At each workstation, the client application runs on the multi-touch tabletop and the augmented 3D application named "3DAPP" runs on the vertical display.

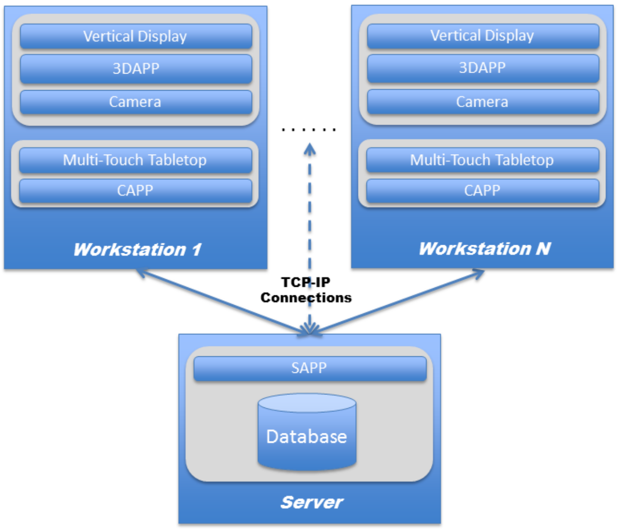


FIG. 8 NETWORK ARCHITECTURE OF THE DISTRIBUTED MTMR SYSTEM

In this networked system, the server application is designed as a data synchronization manager and communication coordinator. It is mainly responsible for storing project information, keeping track of session information and directing messages among different clients. For each project, it maintains an individual file keeping records of the project meta-data and project scene data. Meta-data includes information that will help server application initialize a new session. Project scene data mainly consists of a list of data structure that represents all objects in the scene. The major attributes that are used to describe each object are object index, type, position, rotation and scale.

Separated View Mode and Extended View Mode

(A) TABLE 1

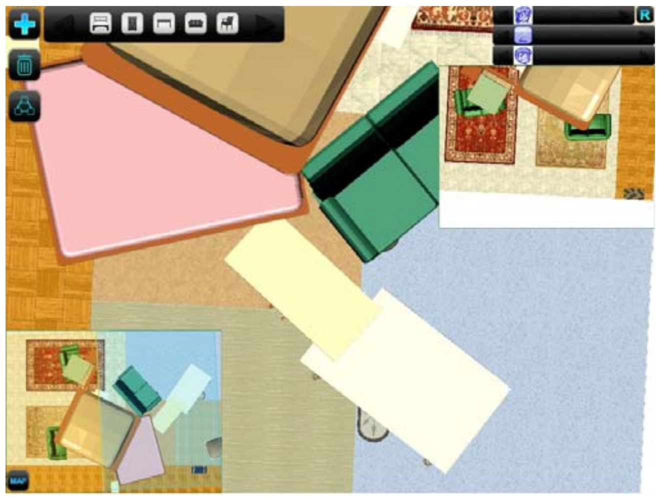
(B) TABLE 2

FIG. 9 A SCREENSHOT OF THE CLIENT APPLICATION RUNNING IN SVM

The system also provides two different collaboration modes to facilitate different collaboration needs, which is enabled switchable by the View Mode Switch widget.

In Separated View Mode (SVM) (See Fig. 9), each multi-touch tabletop can have its own view range of the shared workspace. Workspace manipulation on tabletop A does not affect the view range of tabletop B. But furniture model manipulation on tabletop A is synchronized with the shared workspace and is reflected at other tabletops. In order to keep the integrity of the furniture models in the shared workspace, each model can only be manipulated by the users at the same tabletop. This mode is suitable for most remote collaboration tasks.

In Extended View Mode (EVM) (See Fig. 10), two multi-touch tabletops are virtually concatenated together so that a larger single multi-touch tabletop surface can be constructed just by putting the two tabletops side by side. Both workspace manipulations and furniture model manipulations are synchronized with each other. Workspace and all objects inside the shared workspace can be manipulated by users at different tabletops at the same time. This mode is the most suitable for overcoming the physical constraint of collocated collaboration.



(A) TABLE 1

(B) TABLE 2

FIG. 10 A SCREENSHOT OF THE CLIENT APPLICATION RUNNING IN EVM

A New Touch Gesture for Collaboration in EVM

Assume that a team of designers are collaborating in EVM, and one designer working on one tabletop wants to pass an object to another designer working on another tabletop. Traditional touch gestures cannot achieve this. Thus, a sliding gesture is implemented to improve user experience when they are collaborating in EVM.

We achieve this in three steps. Firstly, the simple

translation gesture is recognized, and the speed of the touched item is estimated. Whenever a translation happens on the item, the intrinsic speed is estimated by dividing the displacement with time difference. The new estimated speed is calculated by taking the average of the intrinsic speed and the previous estimated speed. Secondly, when the finger is removed from the item, the estimated speed is then used as the start value of the sliding animation. The animation is played to indicate the sliding operation and the speed is reduced in a quadratic curve. Finally, when the object is passing through the boundary of one tabletop and entering another, the server application plays data synchronization, simulating that the object is seamlessly passing between two virtually concatenated tabletops.

User Avatar System

FIG. 11 A SCREENSHOT OF THE USER AVATAR SYSTEM AT TABLE 1

In order to solve the user awareness problems in remote collaboration, a user avatar system enabling following functionality is implemented (See Fig. 11):

- A list widget for showing the icons of all workstations that have joined in the current project.
- A list widget for displaying the avatars of all participants that are registered on a selected workstation.
- A mini view widget for displaying the remote workspace view of a selected remote workstation.
- It is able to display a user's avatar on the object that the user is currently touching on.
- It provides a short animation to enlarge the user avatar of an object that a user touches in the mini view widget.

The main benefit of the user avatar system is that it allows a user easily recognizes the existence and manipulation of another remote user without having any interfering effects on this user's own manipulation.

Example User-Case Scenario

MTMR system is a conceptual design framework that utilizes an enhanced information visualization method (3D MR) to improve users' experience on indoor spatial information rendering, which is believed to be helpful for interior design. Besides, the application at client side provides an opportunity for the client to view the temporary design easily and intuitionally.

Moreover, the extension of the MTMR system for collocated and remote collaboration is aimed to solve the problems such physical limitation of single tabletop and remote user awareness which are common in currently developed multi-touch tabletop based CSCW projects.

To show the use of our system, we describe a scenario in which a large designer team, whose members are located in different places, is carrying out an interior design for a remote client. We will explain how our design features are used as we follow how the designer team carries out the design work.

Communication between Designer and Client

Suppose that a designer team works in Singapore, carrying out an interior design job for a client in China. The client needs the design team to send the detailed information about the room, such as its height, width and shape. Using the proposed MTMR system, members of the designer team can do the job by co-located collaboration or remote collaboration on the distributed tabletop (introduced later). After the initial design is completed, the design team sends the client the information about the design, and then, the client can use the proposed application at the client side to view the vivid live video of the current design on his laptop, which offers the client an opportunity to give instant and helpful feedback.

3D MR

During the design, the designer may need to take into account the effects of the furniture's height played on the room. Without the vertical display in our system, it is difficult for the designers to achieve this because

most tabletop displays can only provide 2D information (the height and the width). Although by adding a rotation gesture and the relative object rendering with respect to the slant and tilt direction, it is possible to implement 3D simulation in the tabletop display, this newly added gesture will make impossible the collocated collaboration on a single tabletop or distributed tabletop in EVM mode. This is because certain designer's manipulation using the slant and tilt gesture will always distract others who share the same workspace from their work.

Thus, the vertical display and its 3D MR simulation is a reasonable way for the designer to view the 3D spatial information of their design. It won't lead to any distraction to others, since the rendering of the perspective view has no effects on the manipulation workspace.

Collocated and Remote Collaboration

Suppose that there is the designer team includes six designers, four in Singapore are in charge of placing the furniture; another two in Hong Kong are in charge of paining the floor. The four in Singapore need two tabletops, one displays the eastern part of the room and the other western part. These two tabletops are in EVM which enlarges the workspace to allow them to work concurrently. If one designer finds that the furniture object which is under manipulation of his colleague, is also suitable for the space he is in charge of, he can ask his colleague to pass the object via the sliding gesture.

The two in Hong Kong and in charge of painting floor only need one tabletop. Since the placing of furniture has great effect on the final outlook of the floor, they need to remotely collaborate with the four in Singapore. However, instead of EVM, SVM is activated in the tabletop because they need a whole view of room to efficiently paint the floor. Sometimes, the manipulation of the furniture may distract their painting. When this happens, the user avatar system provides them with information about who are manipulating the distracting furniture so that they can call the corresponding designer in Singapore to stop for a while via the speech communication system.

Conclusions

We have developed MTMR, a conceptual interior design framework which integrates MR with the multi-touch tabletop interface, to provide an intuitive and efficient interface for collaborative design and an augmented 3D view to users at the same time. Moreover, we have extended the MTMR system for both collocated and remote collaboration.

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